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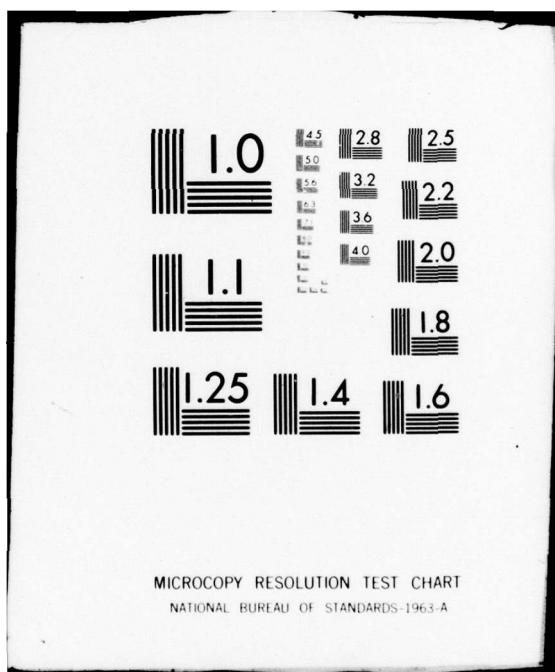
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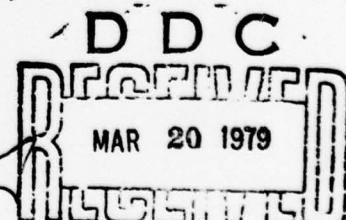
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SIMPLE ACOUSTIC EMISSION TESTS FOR THE
DETECTION OF CORROSION

10 by
Ian D G SCOTT and L. WILSON
Lance Wilson

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**SIMPLE ACOUSTIC EMISSION TESTS FOR THE
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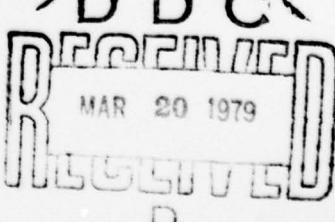
by

I. G. SCOTT and L. WILSON

SUMMARY

Simple acoustic emission equipment was used for laboratory tests on corrosive systems. Although the precise source of the acoustic emission is not yet known, these tests demonstrated the potential usefulness of the technique for the detection of active corrosion.

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1. INTRODUCTION

Acoustic emission (AE) arises from energy redistribution within a system. For example, it can be detected at the surface of a solid during deformation as some energy appears as elastic waves which propagate with the speed of sound. Again, copious AE occurs during many temperature-induced martensitic transformations in solids. Some materials emit AE during a change of state.

Chemical reaction involves a redistribution of energy, and consequently, it seems reasonable to look for AE during this process. The chemical reactions of most interest in these laboratories are those associated with corrosion.

2. PREVIOUS WORK

Relevant information from a number of minor references¹⁻⁷ has been summarised in Table 1. It appears that AE from corrosion can be detected under various conditions and that bubble formation associated with boiling or cavitation also produces AE. Several authors postulate that AE associated with corrosion is due to bubble formation.

Wilson *et al.*⁸ immersed aluminium foil in tap water; as corrosion took place, holes formed in the foil, bubbles were observed and AE was recorded. Good correlation between rates of hole formation and AE counts was found. Later tests with a Daniell cell showed that AE from metal dissolution could only be detected with difficulty. Mah *et al.*⁹ detected AE from uranium-niobium alloy specimens immersed in various liquids. Corrosion was detected in the presence of chloride ion concentrations as low as 5 ppm. Takano and Ono¹⁰ measured AE during electro- and electroless plating and identified two types of behaviour. One type related to the formation of cracks during plating and was associated with very high AE count rates (up to 5×10^5 /min). The other type of behaviour referred to the formation of hydrogen bubbles (count rate below 10/min) and also to the deposition of chromium, copper and nickel; these deposited layers may have contained very small cracks which could not be seen using an optical microscope. The observed AE during the plating of copper was about 100 counts/min, even though the hydrogen evolution observed was negligible. Thus, AE may well result from the plating operation alone. Rettig and Felsen¹¹ detected AE from iron and aluminium specimens immersed in salt solution and demonstrated an increase in AE when the specimens were in contact with each other. An effect of chromate ions on the corrosion rate of aluminium specimens in salt solution was also shown. Rettig and Felsen discussed the use of AE to detect active corrosion in bonded joints and honeycomb material, no mention being made of bubbles.

Rodgers and Moore¹² injected potassium hydroxide and hydrogen peroxide solutions into a honeycomb material bonded between aluminium sheets and detected the formation of both oxygen and hydrogen bubbles. A relationship between the size of bubble and AE was claimed but not given. A non-destructive inspection technique for locating areas of corrosion beneath the skin was developed, based on accelerating the corrosion by heating. Heat conduction of the honeycomb material was very poor, so that a small area (about 0.1 m^2) of skin could be readily heated to 60°C with a hot air gun.

The various workers above have been able to associate AE with corrosion but the source of AE, the relationship between corrosion rate and AE, and the overall sensitivity of detection are all unknown. Nevertheless, even at this present stage of understanding, it appears that AE is a suitable tool for comparing corrosion activity in certain systems. Development of suitable equipment for laboratory use was therefore undertaken.

3. DESCRIPTION OF EQUIPMENT

The equipment for the present study was required:

- (i) to provide an AE system by which corrosion activity could be monitored;
- (ii) to permit the comparison of AE activity from more than one source of corrosion, and
- (iii) to allow unattended operation over long periods of time.

The AE equipment (Fig. 1) comprised a pair of piezo-electric transducers having a resonant frequency close to 60 kHz. The transducers were alternately connected to a preamplifier by means of a reed relay driven from a very low frequency square-wave generator (period about 3 mins). The preamplifier comprised a high input impedance FET stage followed by low noise transistors and an IC operational amplifier. The filter which followed was designed to have a band-pass centre frequency of 60 kHz. The main amplifier was provided with a continuously variable attenuator. The maximum available gain was in excess of 120 dB although this level was never used.

The ring-down counting technique (Brindley *et al.*¹³) gives an excellent indication of AE activity. In early experiments, a counter feeding a D-A converter was used to count signal excursions above a preset threshold. The converter was used in conjunction with an X-Y plotter to record count rates for periods up to 30 mins. In later experiments, a count-rate indicator (Scott¹⁴) was used, outputting to a strip chart recorder. The count-rate indicator produces a DC voltage output which is proportional to total counts, and was developed as a counter replacement. Input signals above a preset threshold were converted to logic pulses. The fraction of time these pulses were in the 'high' state was determined by means of an integrating circuit. The indicator was arranged to reset at regular short intervals (about 3 sec) so that a measure of count-rate was obtained.

Only solid-liquid systems have been examined; the solid and corrodent were contained in covered specimen bottles placed on transducers to which they were acoustically coupled via a layer of grease. Consideration was given to the construction of special flat-bottomed corrosion cells but the simple system has so far been quite satisfactory.

A simple single-transducer device, using essentially the same circuits but having a meter read-out, has been developed for field studies of corrosion.

4. EXPERIMENTAL WORK

The equipment has been in use for several years for assessing the effect on aircraft materials of various substances.

(i) Disinsectants

Two compounds, d-phenothenrin and permethrin, have been proposed as alternative formulations to pyrethrins/DDT for the disinsection of aircraft. The corrosive potential of these substances towards aluminium alloy 2024-T6 (one of the most corrosion-prone of the aluminium alloys used in aircraft structures) was studied. Tests were performed using distilled water, tap water, the disinsectants and also mixtures of 0.005, 0.05 and 1.0% disinsectants with distilled water. (It was considered possible that, when mixed with condensate within the aircraft, the disinsectants might hydrolyse to form corrosive compounds.)

Aluminium alloy specimens 50 × 25 × 12 mm polished to a 600 grit finish and degreased, were used. Specimens were tested in pairs for a period of four days after which a different specimen-corrodent combination was examined.

It was observed that

- (a) the specimen in tap water started to corrode immediately;
- (b) the specimens in distilled water corroded two to three hours after immersion; and
- (c) the specimens immersed in the various disinsectant solutions emitted no signal even after four days immersion.

These results were confirmed by visual and weight-loss corrosion tests.

(ii) Cleaners

Chlorinated hydrocarbons, such as perchlorethylene and trichlorethylene, are often used to clean aircraft components during and after manufacture. Although proprietary cleaners based on these compounds also contain stabilisers, the possibility of the compounds decomposing to form hydrochloric acid has long been of concern. Although dry chlorinated hydrocarbons and metals in bulk do not react together under normal conditions, a reaction will take place in strong ultra-violet light. Investigations were therefore made on the effect of sunlight on perchlor-

ethylene and trichlorethylene. Two bottles, each containing one of the chlorinated hydrocarbons, were placed in direct sunlight. The presence of acid was indicated by pH measurement—a sample of the mixture was removed and shaken with an equal volume of water. The pH of the aqueous layer, containing acid extracted from the mixture, was measured.

In two separate bottles, a coupon of magnesium, 50 x 25 x 12 mm polished to a 600 grit finish and degreased in alcohol, was covered with one of the chlorinated hydrocarbons. Each bottle was tested first in strong sunlight and then in total darkness. Two to three days elapsed before a significant indication of the presence of acid in the compounds exposed to sunlight was observed, while acoustic emission signals from the coupons were detected almost immediately. No effects were observed from the tests conducted in the dark even after one week.

(iii) *Lubricants*

During the overhaul of some aircraft engines, many magnesium alloy centre casings were found to be severely corroded. Preliminary investigations suggested that a barium chromate-inhibited silicone grease either alone or in combination with a particular engine oil may have been responsible for the corrosion.

A specimen cut from portion of a centre casing was coated on one side with grease, a transducer was attached to the other side and records were taken for two days. No AE was detected. The grease-coated specimen was then placed in a jar containing the suspect oil and records were taken for a further two days. No AE was detected. These results indicating no corrosion were confirmed by visual and weight-loss corrosion tests.

5. CONCLUSIONS

It is concluded that simple laboratory equipment can be constructed for use in corrosion-AE studies. The potential of the AE technique is apparent—not only does it permit the detection of corrosion well before it can be confirmed by other means but continuous recording is possible. Hence changes in corrosion with time can be studied. There are still obvious areas calling for further work: e.g. the source of AE has not yet been established and until this has been done there is little likelihood of predicting AE outputs from knowledge of components of the corroding system. As well, it is not presently possible to relate AE and corrosion rates. Nevertheless, even in its present state of development the technique has many obvious advantages.

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TABLE I
Summary of Minor References Appropriate to Corrosion and AE

Reference	Process	Remarks
Anderson ¹	Boiling of liquid sodium in nuclear reactor.	AE detected but source hard to identify.
Hutton ²	Turbulent flow in hydraulic system. Cavitation and turbulent flow in system.	Source clearly identified; low frequency AE. AE signals increased fifty-fold.
Okada <i>et al.</i> ³	Various steel specimens immersed in boiling MgCl ₂ . Hydrogen induced micro-cracking at advancing crack tip. Anodic dissolution of steel specimens.	AE detected and eliminated by filtering. High amplitude AE detected. No AE expected (and none observed).
Balderton ⁴	SCC specimen of 7079 T651 alloy wetted with 3% salt solution; no observable cracking.	AE observed; assumed to arise from corrosion.
Chakrapani <i>et al.</i> ⁵	Unstrained specimens of Mg-Al alloy immersed in an aqueous solution of 4% NaCl and K ₂ CrO ₄ .	Observed bubbles assumed to be of hydrogen along with continuous AE signals; signals from cracking were spike-like and of much higher energy levels.
Cox ⁶	Zircaloy-2 immersed in 5% NaCl solution; various solution potentials applied.	AE count rate was a function of solution current but varied for constant current; with specimen cathodic, found continuous AE from hydrogen evolution; with specimen anodic found AE either from metal dissolution or oxygen evolution (no gas was observed).
Schofield ⁷	Single crystals of Al immersed in etchant solution; various solution potentials applied.	During removal of metal profuse bubbles were observed along with many high energy bursts of AE; on reversing polarity there were profuse bubbles but AE was continuous and related to bubble formation and collapse.

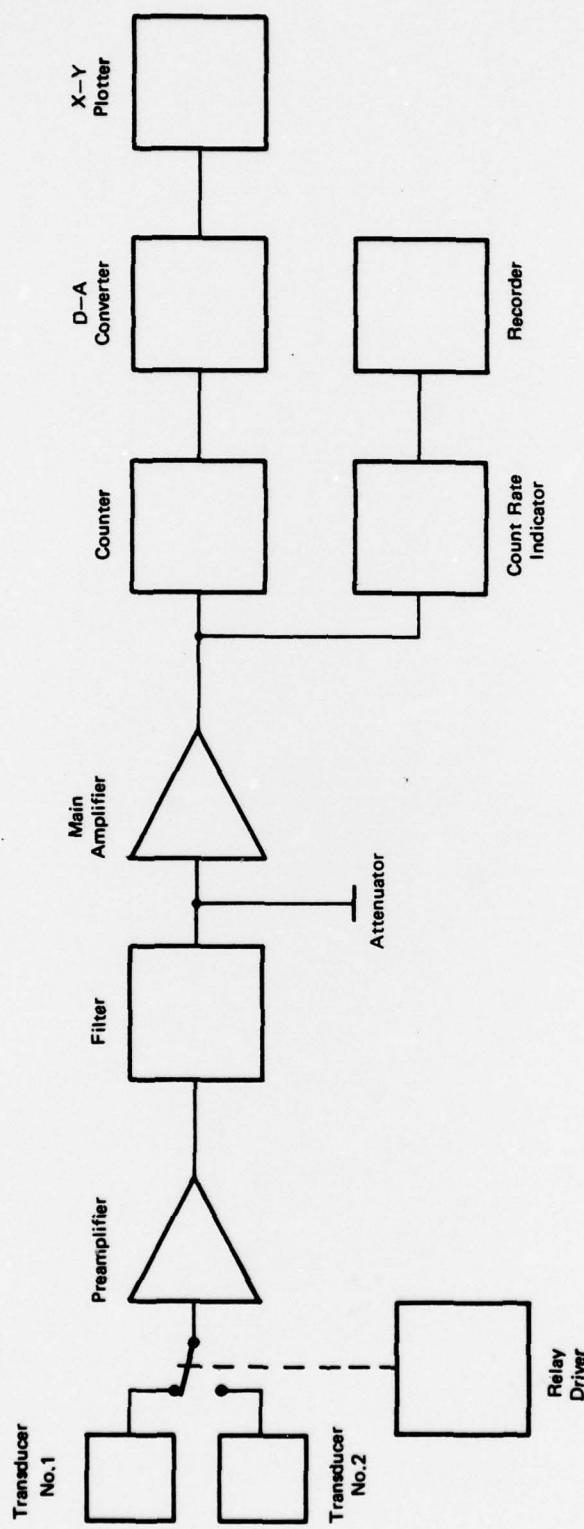


FIG. 1 SCHEMATIC DIAGRAM OF AE EQUIPMENT

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ABSTRACT

Simple acoustic emission equipment was used for laboratory tests on corrosive systems. Although the precise source of the acoustic emission is not yet known, these tests demonstrated the usefulness of the technique.

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